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Original Article

THE DESIGN & CONSTRUCTION OF AN AUDIOMETER WITH BUILT-IN ASSISTIVE DIAGNOSTICS

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ABSTRACT

A low-cost Audiometer was designed and constructed for carrying out primarily, Pure Tone and Speech Audiometry. The Audiometer also included other standard subjective behavioural tests: Tone Decay, SISI (Small Increment Sensitivity Index), ABLB (Alternate Binaural Loudness Balance) Test and Stenger's. Other standard features offered were: output transducer options: Air Conduction Headphones, Bone Vibrator, and Free Field output, Contralateral Masking, Audiogram (during Pure Tone test) on instrument's LCD display, battery operation.

In addition to the standard features, the Audiometer introduced two features:

One, Assisted Diagnostics. It interpreted the tests conducted on a patient, based on information in the public domain, to point out which part of the auditory system may be malfunctioning ("site of lesion"). The diagnosis was suggestive rather than prescriptive, with the aim of assisting the audiologist or clinician conducting the tests. For example, in a simplest test inference, audiometer classified type of hearing loss: Mild, moderate, severe, profound or total, based on generally accepted criteria.

Two, Automatic Calibration to correct for output transducer's acoustic characteristics.

It was suggested that this built-in diagnostics could be made more exhaustive and reliable, using Artificial Intelligence tools.

Except for PCBs designed by the authors, all components used in the project were standard, low-cost, available in the market.

KEYWORDS: Audiometer, Audiometry, Audiogram, Auditory system, Hearing Loss, Diagnostics & Artificial Intelligence

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INTRODUCTION

Audiometer helps evaluate hearing impairment in humans, the process of doing so is called audiometry [5]. Audiometer generates essential auditory test signals [2] which are applied to patient's ears or mastoid through transducers like air conduction headphones, or bone vibrator or simply broadcasted through loudspeakers. The type and extent of hearing impairment can be determined from response of the patient to these auditory signals.

While audiometer is used for subjective, behavioural tests, instruments like Tympanometer are used for objective tests, which measure ear's impedance characteristics.

Hearing impairment in humans can be due to problems with any part of our ears: the outer ear (auricle, ear canal, ear drum outer layer), the middle ear (eardrum inner layer, the ossicles), or the inner ear (cochlea) – the auditory system – or even beyond in the nerves leading to the brain. Since all these parts are in 'series' (Figure 1),

malfunction in any part leads to hearing impairment. To determine which part may be defective, researchers over the years have developed 'tests' which help in the location of the defect within an auditory channel. Tests are combinations of test signals, delivered to human ears in a specific order.

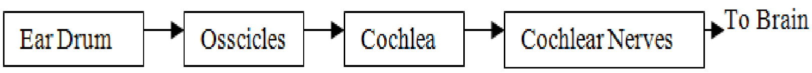


Figure 1: The Auditory Channel – A Series Combination of Functional Units

Hearing loss can simply be age related, or noise induced, temporary or permanent, general or specific at certain high or even low frequencies, abnormally non-linear.

Many of these problems can be diagnosed by professionals using just a tuning fork or a range of electronic instruments like Audiometer and Tympanometer, based on testing methods devised by researchers working in the field over the years.

A large range of sophisticated Audiometers are available in the market, varying in features, specifications, and prices.

This paper concerns the design and construction of a low-cost Audiometer. Objectives of design are:

- Low Cost design. This is to be realized by making the circuit compact and simple, and using standard components.
- Developing a system of automatic calibration.
- Building-in a system of diagnostics. Normally, clinician who carries out audiometry tests, studies test results and makes a diagnosis. Design objective here is build-in the logic needed to diagnose test results.

The interpretation is based on current knowledge in the field of audiometry, and interpretations given by researchers in the field [3][4][9].

DESIGN & CONSTRUCTION

(Appendix lists basic specifications to which audiometer is designed)

Block diagram: Figure.2 below shows simplified block diagram of the Audiometer

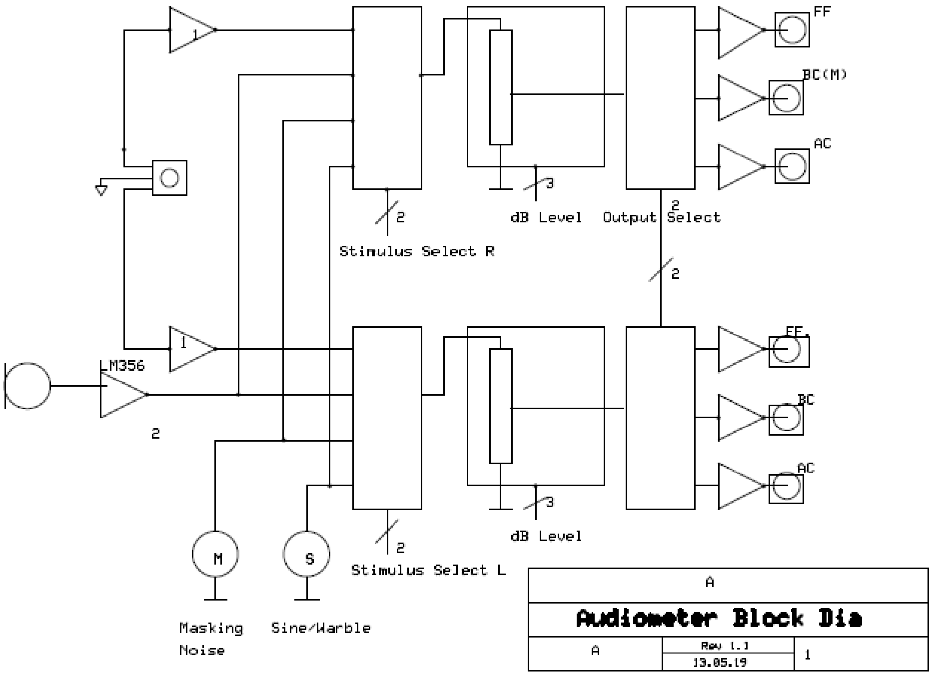


Figure 2: Block Diagram of The Audiometer

Test Signals Generated by The Audiometer

- Sinusoidal, Continuous waveform

This is also called Pure Tone. It is generated by a digitally controlled IC working on DDS (Direct Digital Synthesis) principal.

- Pulsed Tone

This is a discontinuous, pulsed sine wave. On -Off periods of sine wave are standard, 200ms.

- Warble Tone

This is a continuous, frequency modulated sine wave. This is digitally realized by varying the test frequency in 1% steps, with a maximum of ± 5%, with a timing such that the complete cycle of ± 5% change is completed in 0.2 second. Thus, there are five frequency modulation cycles per second.

Components

All components in the block diagram i.e. Microcontroller, Sinewave generator, Masking Noise generator, Attenuator, Output Amplifiers, Test Signal Selector & Output Switching, Op Amps, Rectifier, Voltage Regulator, Positive to Negative Voltage Converters were implemented by commercially available integrated circuits. The three key components were:

Microcontroller used was PIC30F50xx series, 64 pin

Sine Wave Generator: DDS IC AD983x from Analog Devices

Attenuator: Digital Potentiometer from Texas Instruments, Resolution 0.5 dB, Range: 96 dB

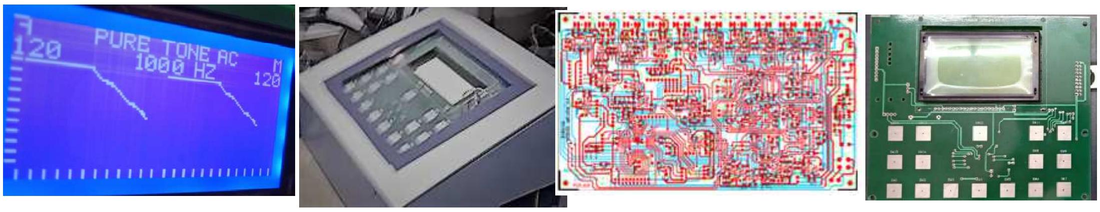
Audiometer operated from external single +9 V DC and internal 3x3.2 Rechargeable batteries. However the

circuit operated from regulated ±5V, the negative supply was generated using positive to negative DC converter.

A battery charging circuit was included.

All transducers: Microphones (Electret), AC Headphones, and Bone Conductors (B71 or equivalent) were of standard makes available in the market.

Two PCBs were designed, one for accommodating touch keys plus display, and the other a mixed signal PCB for all analog and digital components (Figure 3)



a **b** **c** **d**

Figure 3: Images From Construction
a. Audiogram Display, b. Box,
c. Audiometer's Motherboard, d. Capacitive Touch Keyboard

PC Connectivity

Audiometer communicated with a Laptop or Desktop though built-in USB connectivity. It made to possible to draw audiogram on PC as the patient was being tested. Internal memory being limited, Patient test data and personal details were saved on PC. Audiogram could be printed directly from PC.

Calibration

A system to automatically calibrate displayed output w.r.t actual level received in the ear (from AC and BC transducers at various frequencies) was designed. The calibration process corrects any piece-to-piece variations in output transducers, or changes in their outputs over time. The system involved measuring actual acoustic output, adding a 'hidden' offset to equate actual output with user-set displayed output.

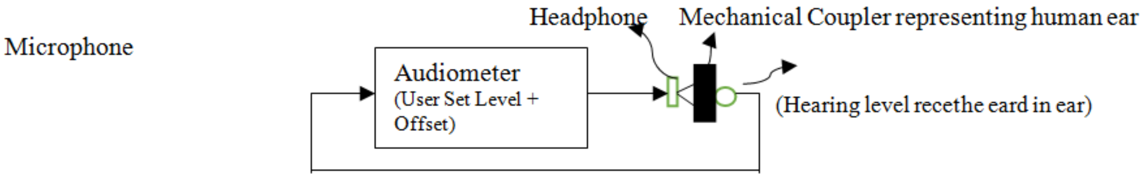


Figure 4: Automatic Calibration Set-Up: Offset = User Set Level – Level Received in The Ear

ASSISTIVE DIAGNOSTICS AND CLASSIFICATION[3][5]

This is based on following table of audiometric (subjective, behavioural, and Speech) tests and inferences, reported in public domain by several researchers.

Classifying and Diagnosing Cause of Hearing Loss [1][3][4].

Table 1: Audiometry Tests and Diagnostic Inferences

Test	Inference (Diagnosis)
Pure Tone	Simple Classification of Hearing Loss[9]: Threshold (Average of 1 to 3 KHz) >91 dBHL : Profound Hearing Loss >70≤ 90 dBHL: Severe Hearing Loss >40≤ 70 dBHL: Moderate Hearing Loss >25 ≤ 40 dBHL: Mild Hearing Loss ≤ 25 dBHL: Normal hearing
Tone Decay Test	High Levels of TD indicate problems beyond cochlea ("Retro-Cochlear pathology") 0.5 dB in 60 s : Normal 10 to 15 dB in 60 s: Mild 20 to 25 dB in 60 s: Moderate
SISI	Score > 70% +ve: inner ear problem (Cochlear pathology) Score < 30% - ve, but if any problem in PT, disorder not in inner ear but somewhere else
Speech: Speech Reception Threshold	If it does not correlate with average PT threshold, possible post-cochlear pathology
Speech: Speech Discrimination Score	Sensori-neural loss or post-cochlear lesions (SDS < 30%)

RESULTS

Test signals generated by audiometer were measured and observed using digital oscilloscope. Sine wave distortion was < 0.1%, and frequency accuracy was within 0.05%. Output of masking noise generator complied with characteristics of white noise. The Audiometer correctly generated essential test signals. Following audiometric tests could be done with this audiometer: Pure Tone, Speech, Tone Decay, SISI (Small Increment Sensitivity Index), ABLB (Alternate Binaural Loudness Balance) and Stenger's. Pure Tone test data was manually plotted [10] for a person and is shown in Figure. 4 below.

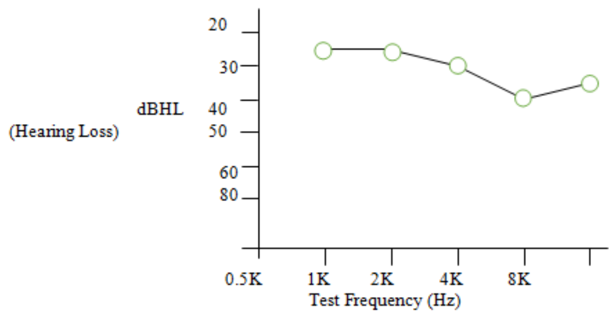


Figure 5: Audiogram Of A Person, Pure Tone Test, Air Conduction (AC), Right Ear
(Note: Audiogram not Shown in Standard Format)

DISCUSSIONS

Determining extent and cause of hearing loss requires a number of behavioural/subjective audiometry tests to be done on the patient. A single test may not be conclusive. Further, objective tests also may be required. Results of tests are evaluated by doctor/audiologist/clinician, and diagnosis made. The logic required to diagnose is now built-in in the Audiometer firmware (based on a limited number of tests). However diagnosis using this logic is for the purpose of aiding the clinician and is not prescriptive.

CONCLUSION AND FUTURE SCOPE OF WORK

A low-cost audiometer was designed and constructed. It featured built in assistive diagnostics to help audiologist or clinician to localise problem in auditory system. Audiometer also included an automatic calibration system.

This audiometer has a few limitations, in order to keep costs low. For example, it is not a true two-channel audiometer. It has a small number of an otherwise large battery of tests developed over the years. To make the audiometer more useful.

- More specialized hearing tests need to be included in the audiometer [2][4]
- More exhaustive use to be made of current knowledge in the field[2][4]
- More use of AI tools to be made to correlate various tests and arrive at more accurate diagnosis [3][7][8] [9]

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APPENDIX

Table 2: Specifications: Diagnostic Audiometer Type 2[11]

Sr No	Parameter	Value
1	Channels	2:(One for stimulus, other for Masking)
2	Tests	Pure Tone, Speech, SISI, TD, ABLB, Stenger
3	Oscillator	1
4	Waveform Distortion	< 0.1%
5	Frequency Range	125 Hz to 8 KHz
6	Tone	Continuous sine, Pulsed, Warble
6	Accuracy of dBHL	< 0.5 dB
7	O/P Range	-10 to 120 dBHL
8	Masking	Broadband, Contralateral
9	Microphone	2(for Speech Test, Patient Communication (forward & Backward)